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Influences of Mounting Angles and Locations on the Effects of Gurney Flaps

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Experimental investigations were conducted on a NACA0012 airfoil to determine the influences of mounting angles and mounting locations on the lift-enhancing effects of Gurney flaps at a Reynolds number of 2.1 × 10^6. The results revealed that all flaps of different mounting angles increased the lift coefficient, and an increment of maximum lift coefficient of 12.3, 15.1, and 17.4% was obtained by 45-, 60-, and 90-deg Gurney flap, respectively. There was a drag penalty associated with the lift enhancement. The best performance was obtained by the 45-deg Gurney flap for all flap deflections tested. When shifted forward from the trailing edge of the airfoil, the Gurney flap led to a decrease in lift, and an increment in drag, and thus a reduction in lift-to-drag ratio.

Nomenclature

C_d	=	drag coefficient
C_l	=	lift coefficient
C_m	=	quarter-chord pitching moment coefficient
C_p	=	pressure coefficient
c	=	chord length
h	=	Gurney flap height
L/D	=	lift-to-drag ratio
s	=	distance between mounting location and trailing edge of the airfoil
u/U	=	measured/freestream velocity
x	=	streamwise direction
z	=	normal direction
α	=	angle of attack
Φ	=	mounting angle

Introduction

THE Gurney flap is a short strip placed along the trail edge of a wing, perpendicular to the chord line or the pressure surface. Its main purpose is to increase the lift generated by the wing.

Experiment on Gurney flaps was first reported by Liebeck,[1] conducted on a Newman symmetric airfoil with a 1.25%c Gurney flap. Liebeck[1] found that the flap increased the lift while the drag was slightly decreased. He also proposed a hypothesized flowfield at the trailing edge of an airfoil with Gurney flap. This flowfield was later qualitatively confirmed by Neuhart and Pendergraft,[2] who conducted a water-tunnel study on Gurney flaps, testing different configurations on a NACA0012 symmetrical airfoil at a Reynolds number of 8.5 × 10^3. In the water tunnel the Gurney flap provided an increased region of attached flow on the wing upper surface with a recirculation region behind the flap. This is consistent with the reduced form drag obtained at high lift coefficient using a Gurney flap.[1] The tests performed by Storms and Jang[3] showed that the lift was substantially increased with the Gurney flap while the drag was decreased at high lift coefficients, but the drag was increased at low to moderate lift coefficients. Myose et al.[4,5] measured surface-pressure distributions and wake profiles on airfoils, wings and reflection plane model with Gurney flaps, and acquired significantly improved performance. Giguère et al.[6] suggested that the increase in lift with Gurney flaps is obtained with very little penalty in drag because they reside within the airfoil's boundary layer. Based on their results as well as a review of past studies, they found that the maximum lift-to-drag ratio could be obtained when the Gurney flap height was equal to the boundary-layer thickness. Jeffrey et al.[7] conducted Laser Doppler Anemometry (LDA) measurements downstream of a Gurney flap, and the data showed that the wake consists of a von Kármán vortex street of alternately shed vortices. The vortex shedding increases the suction at the trailing edge on the suction side of the airfoil; on the pressure side the Gurney flap decelerates the flow and thus increases the pressure. The pressure difference that results across the trailing edge generates the increase in the airfoil's circulation, and thus the lift.

Bloy and Durrant[8] and Bloy et al.[9] found that the performance of an airfoil with a 45-deg Gurney flap was superior to the same wing with a similarly sized 90-deg Gurney flap. Both types of flaps significantly increased the maximum lift of the NACA63$_2$-215 airfoil, although the 45-deg flap produced less drag than the 90-deg flap. Of the flaps tested a 2%c 45-deg flap produced the highest lift, with the lift-to-drag ratio higher than that of the airfoil with the 90-deg flap over the entire angle-of-attack range. The peak lift-to-drag ratio with the 45-deg flap was comparable to that of the wing without flap, but at a higher lift coefficient.

Storms and Ross[10] and Carrannanto et al.[11] performed experimental investigations and computational simulations on a NACA63$_2$-215 model B airfoil with Gurney flaps. The results revealed that when shifted forward from the trailing edge of the airfoil the performance of the Gurney flap on lift augmentation will be reduced.

As indicated by the surveys already mentioned, there have been a number of studies on the effect of Gurney flaps. However, these studies have been mostly limited in constant mounting angles and mounting locations. Thus, the purpose of the present study was to test and compare Gurney flaps with different mounting angles and mounting locations and to discuss the physical mechanism of lift enhancement using Gurney flaps. The results discussed in this paper are part of a large study on the effect of Gurney flaps. Other results were discussed in Refs. 12 and 13.

Experimental Setup

The experiments were conducted in the NF-3 low speed wind tunnel at the Center for Aerodynamic Design Research (CADR) of Northwestern Polytechnical University (NWPU) of China. This facility is a direct-circuit wind tunnel incorporating a test section 8 m long with a constant height of 1.6 m and a width of 3 m. The test-section turbulence intensity level is less than 0.045%, and the maximum speed of the wind tunnel is 130 m/s. All data were obtained at a freestream velocity of 30 m/s, yielding a Reynolds number based on the chord length of 2.1 × 10^6.

The NACA0012 airfoil used in the experiments had a chord length of 1 m, spanning the 1.6 m height of the wind tunnel (Fig. 1). A

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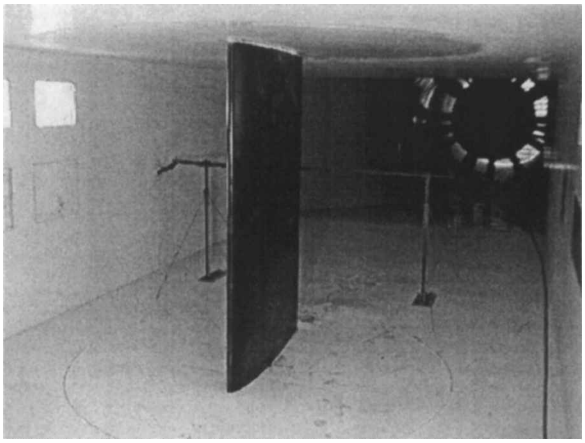


Fig. 1 NACA0012 airfoil in NF-3 wind tunnel.

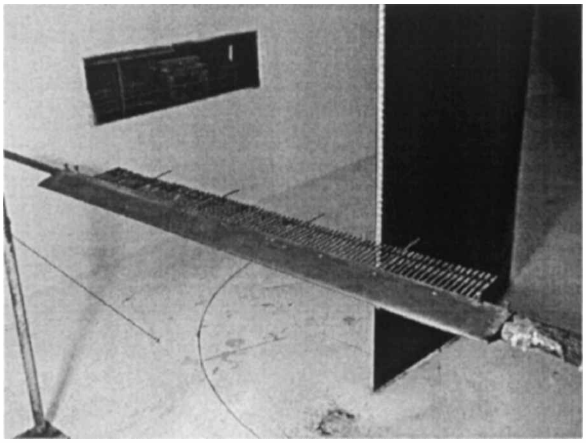


Fig. 2 Wake probes located at 70% chord behind the trailing edge of the airfoil.

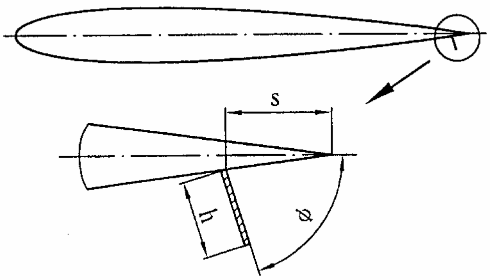


Fig. 3 Gurney flap configuration.

total of 62 surface pressure taps locating at midspan on upper and lower sides of the airfoil were available for airfoil pressure distribution measurements. The lift and pitching-moment coefficients were determined by an integration of the centerline pressure distribution. The drag coefficient was determined by an integration of the static and total pressure measured with a rake situated 0.7 chord downstream of the airfoil trailing edge. The rake, which was located horizontally at the midspan of the airfoil, was composed of 91 total- and 4 static-pressure probes distributed equally over 0.9 m (Fig. 2). All pressures were scanned electronically using Pressure Systems, Inc. (PSI) 8400 System Processor.

The Gurney flaps were mounted to the trailing edge on the pressure side of the airfoil and a height of 1.5%c, as shown in Fig. 3. There were three mounting angles tested—45, 60, and 90 deg—and the distances between mounting location and trailing edge were 0, 2%c, 4%c, and 6%c, respectively. The airfoil was pitched about its quarter-chord location using the motor-driven base plates on the two-dimensional wall inserts. The airfoil angle of attack was arranged from 0 to 18 deg, with increments of 2 deg.

The accuracy of the pressure measurements is higher than 0.05%, and the angle of attack can be set to within ±0.01 deg. The dynamic pressure of the wind tunnel was set to a constant value to maintain a constant freestream velocity, and its accuracy is about 0.1%. As the main purpose of the tests was to obtain the influences of mounting angles and locations of Gurney flaps, the interference of the tunnel walls was not determined.

Results and Discussion

Mounting Angles

The studies on different mounting angles were carried out on a $h = 1.5\%c$ Gurney flap mounted at the trailing edge of a NACA0012 airfoil ($s = 0$), and the mounting angle was 45, 60, and 90 deg, respectively.

The variation of the lift coefficient C_l with angle of attack α was shown in Fig. 4. Compared with the clean airfoil, all flaps of different angles produced increased lift coefficient, and the increment became more significant with the increase of mounting angle. The figure also showed that the stall angle was decreased while the zero lift angle of attack appeared to become increasingly more negative as a larger mounting-angle Gurney flap was utilized, but the slope of the lift coefficient curve remained nearly unchanged. The maximum lift coefficient was increased 12.3, 15.1, and 17.4% for 45-, 60-, and 90-deg Gurney flap deflection, respectively. Note that the stall angles of all mounting-angle flaps are exactly 12 deg and that of the clean airfoil is 14 deg, rather than somewhere in between 12 and 14 deg (Ref. 14). This is probably caused by the somewhat large increment, 2 deg, in angle of attack around stall angles, and thus the actual points were not well captured. The pressure distribution at 4-deg angle of attack was shown in Fig. 5, which indicated that when the mounting angle was changed from 45 to 90 deg the pressure distribution of the suction side of the airfoil was less affected, but the pressure of the pressure side was increasingly increased, and the lift was thus increased.

Figure 6 showed that there was a drag penalty associated with the lift increment, and higher drag was obtained when a larger mounting-angle Gurney flap was utilized. This drag penalty was shown clearly

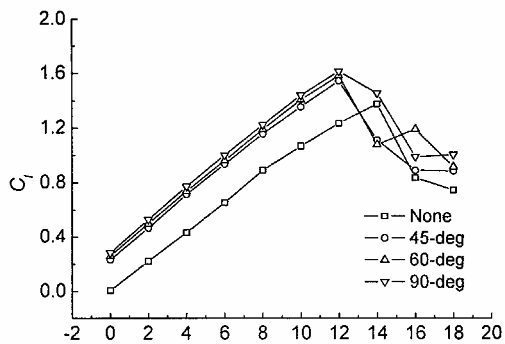


Fig. 4 C_l vs α (changing mounting angles).

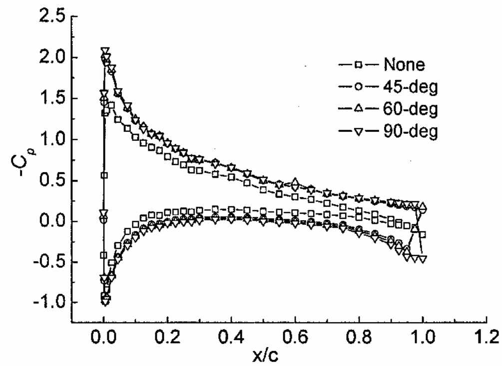


Fig. 5 Pressure distribution (changing mounting angles, $\alpha = 4$ deg).

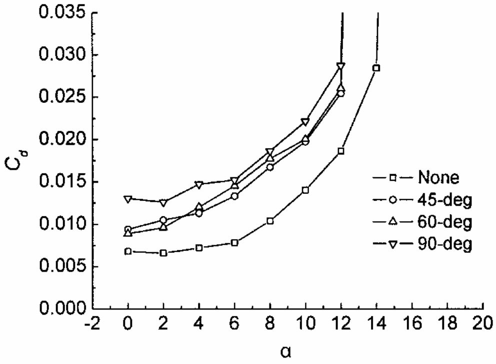
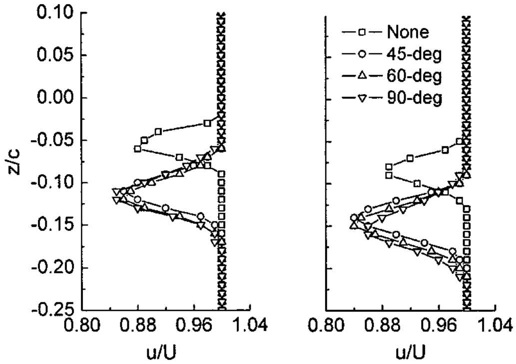


Fig. 6 C_d vs α (changing mounting angles).



a) $\alpha = 4$ deg b) $\alpha = 6$ deg

Fig. 7 Wake velocity profiles (changing mounting angles).

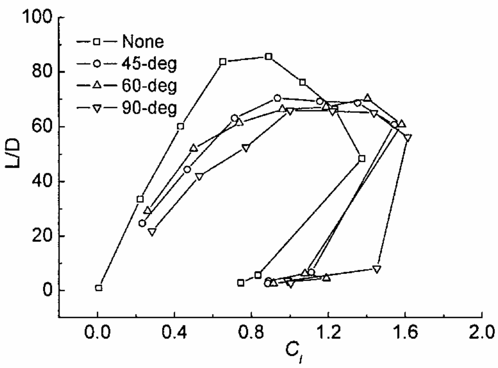


Fig. 8 Lift-to-drag ratio vs C_l (changing mounting angles).

in Fig. 7, from the wake velocity profiles of the NACA0012 airfoil with Gurney flaps of different mounting angles. The profile was shifted downward when a Gurney flap was utilized compared with the clean airfoil, and furthermore, the wake momentum deficit was deeper and wider with a larger mounting-angle Gurney flap. This led to a greater increment in drag than the smaller mounting-angle Gurney flaps.

The lift-to-drag ratio vs lift coefficient was shown in Fig. 8. Enhanced lift capability was accompanied by a reduction in the lift-to-drag ratio at low to moderate lift coefficient, such as $C_l < 1.2$. This was clearly observed for the 90-deg flap, which had the lowest lift-to-drag ratio. Further improvement in the performance was obtained from the 45-deg flap, which had the highest lift-to-drag ratio among the tested flaps. At a higher lift coefficient $C_l > 1.2$, all tested flaps provided an increased lift-to-drag ratio compared with the clean airfoil, and the maximum lift-to-drag ratio was obtained by the 45- and 60-deg Gurney flaps. The results were in good agreement with that of Bloy and Durrant[8] and Bloy et al.[9]

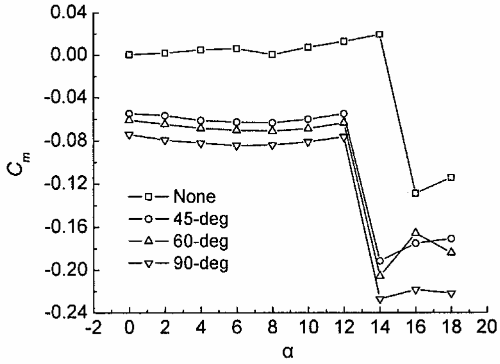


Fig. 9 C_m vs α (changing mounting angles).

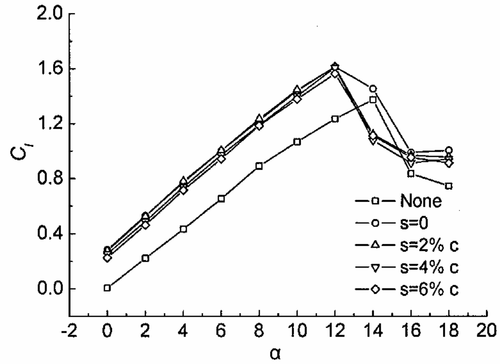


Fig. 10 C_l vs α (changing mounting locations).

The nose-down pitching moment about the quarter-chord line C_m was shown in Fig. 9. The pitching-moment increment appeared to be proportional to the lift coefficient increment caused by the flaps.

Mounting Locations

Investigations were carried out to determine the effects of mounting locations on Gurney flaps. A Gurney flap of 1.5%c was mounted at the pressure side of the airfoil at a constant mounting angle of 90 deg, and the distance between the mounting location and the trailing edge of the airfoil was $s = 0$, 2%c, 4%c, and 6%c, respectively.

Figure 10 showed the lift coefficient of different mounting locations. The lift coefficient was increased, the stall angle and angle of zero lift were decreased when compared with the clean airfoil configuration. However, the increment of lift coefficient decreased as the Gurney flap was shifted forward from the trailing edge of the airfoil, and thus the lift-enhancing effects of the Gurney flap were weakened. For this tested height Gurney flap the maximum lift coefficient was increased 17.4, 17.2, 16.9, and 13.6% when the distance between the trailing edge of the airfoil and the mounting location was selected as $s = 0$, 2%c, 4%c, and 6%c, respectively. The pressure distributions of the tested cases at an angle of attack of 4 deg were presented in Fig. 11. When the Gurney flap was moved forward, the pressure behind the Gurney flap on the lower side of the airfoil turned negative; this revealed the existence of the recirculation region, leading to the abatement of the proportion of the airfoil behind the Gurney flap on lift-enhancement performance. The lift deficit became increasingly more significant at larger distances.

The drag polar (Fig. 12) indicated that flaps of all mounting locations increased the drag when compared with the clean airfoil. Note that the drag was increased remarkably between 2- to 10-deg angle of attack when the Gurney flap was mounted at a location of 4%c or 6%c, and this indicated that the thickness of the airfoil was increased with the presence of the Gurney flap. The wake velocity profile of 4- and 6-deg angle of attack (Fig. 13) also showed a deeper and wider wake momentum deficit as the distance $s > 4$%c, and the drag was thus increased remarkably.

The lift-to-drag ratio was presented in Fig. 14. Similar to the tests on mounting angles, flaps of all mounting locations could not

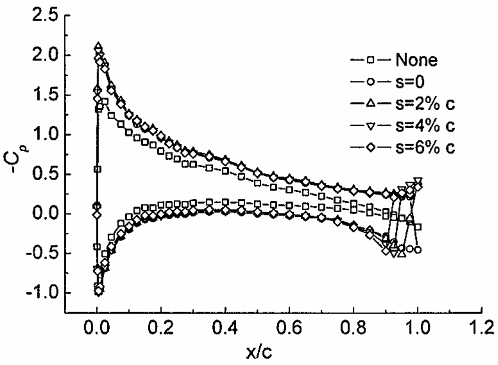


Fig. 11 Pressure distribution (changing mounting locations, $\alpha = 4$ deg).

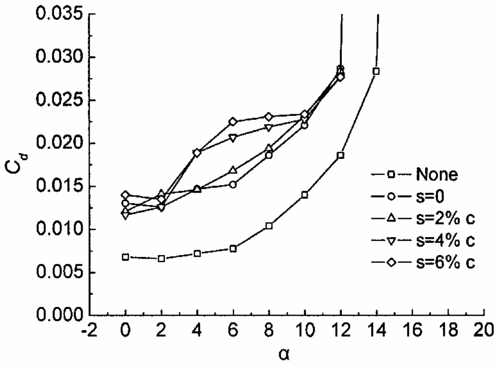
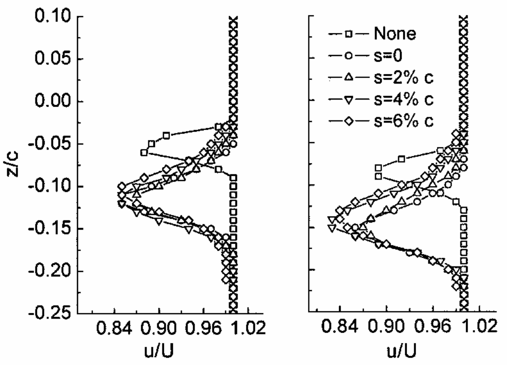


Fig. 12 C_d vs α (changing mounting locations).



a) $\alpha = 4$ deg b) $\alpha = 6$ deg

Fig. 13 Wake velocity profiles (changing mounting locations).

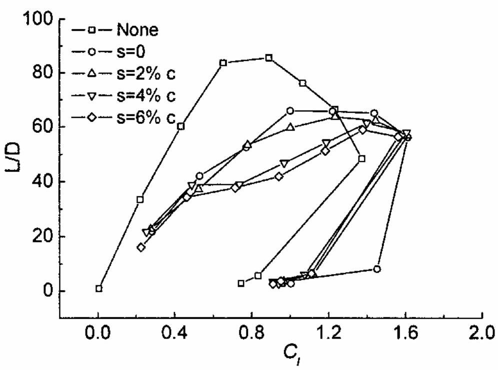


Fig. 14 Lift-to-drag ratio vs C_l (changing mounting locations).

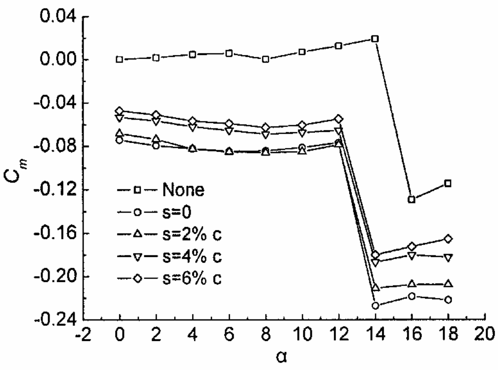


Fig. 15 C_m vs α (changing mounting locations).

provide enhanced lift-to-drag ratio compared with the clean airfoil at a lift coefficient of $C_l < 1.2$, whereas a contrary effect occurred when $C_l > 1.2$. The best performance was obtained at a Gurney flap location of $s = 0$, mounted at the trailing edge of the airfoil. When shifted forward, the effects of Gurney flaps on lift enhancement will be weakened; this is mainly caused by the lift reduction and drag increment caused by the forward moving of the Gurney flap.

Finally, Fig. 15 showed the nose-down pitching moment about the quarter-chord line. The nose-down pitching moment decreased with the forward positioning of the Gurney flap, but still more negative than that of the clean airfoil configuration.

Conclusions

Experimental investigations were conducted on a NACA0012 airfoil to determine the influences of mounting angles and mounting locations on the lift-enhancing effects of Gurney flaps at a Reynolds number of 2.1×10^6. The results revealed that all flaps at different mounting angles increased the lift coefficient, and the increment of maximum lift coefficient of 12.3, 15.1, and 17.4% was obtained by 45-, 60-, and 90-deg Gurney flap, respectively. There was a drag penalty associated with the lift enhancement. The best performance was obtained by the 45-deg Gurney flap for all flap deflections tested. When shifted forward from the trailing edge of the airfoil, the Gurney flap led to a decrease in lift, and an increment in drag, and thus a reduction in lift-to-drag ratio. The drag was increased remarkably between 2- to 10-deg angle of attack when the Gurney flap was mounted at a location of 4%c or 6%c, and this indicated that the thickness of the airfoil was increased with the Gurney flap.

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